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(54) Process for reactivating protein.

(57) Reactivation of cysteine-containing protein in a process, in which a reduced and denatured cysteine-containing protein such as salmon growth hormone I or eel growth hormone I can be efficiently reactivated.

EP 0 302 469 A2

PROCESS FOR REACTIVATING PROTEIN

FIELD OF THE INVENTION

5   This invention relates to a process for reactivating a reduced and denatured cysteine-containing protein.

BACKGROUND OF THE INVENTION

10   A protein is a biopolymer which exerts a specific function through the formation of a definite high-order structure which will be called a "natural form" hereinafter. A disulfide bond between cysteine residues involved in the above-mentioned high-order structure plays an important role in the performance of the function of the protein or in stabilizing the same. Recent development in gene recombination techniques
15   has increased the production of proteins. In an expression system using Escherichia coli, in particular, a protein in the form of inclusion bodies is produced within the cells of the microorganism [cf. F.A.O. Marston et al., BIO/TECHNOLOGY, 2, 800 (1984); and D.N. Brems et al., Biochemistry, 24, 7662 (1985)]. Thus, it is an important problem to collect the desired protein from these inclusion bodies. In order to solubilize these proteinaceous inclusion bodies, it is necessary to once denature the same. When a cysteine-containing
20   protein is to be solubilized, it is necessary to denature this protein in a reduced state. Thus, disulfide bonds should be formed at the same sites as those observed in the corresponding natural protein in order to efficiently reactivate the reduced and denatured protein.
    A conventional process for converting a denatured protein into a natural one in the presence of a denaturing agent is carried out by diluting or dialyzing the starting protein with a solution free from any
25   denaturing agent via one or more steps to thereby reactivate the same [cf. J.A. Gill et al., BIO/TECHNOLOGY, 3, 643 (1985); H.J. George et al., DNA, 4, 273 (1985); and JP-A-61-257931 (the term "JP-A" as used herein means an "unexamined published Japanese patent application)], since this transformation would frequently proceed in two-states [cf. Tanpakushitsu Bunshi (Protein Molecules), 99-127, Iwanami Shoten (1985)]. In this process, secondary and tertiary structures of the protein are also
30   formed at the same time. Thus, hydrophobic groups, which are enclosed in protein molecules in the natural protein, would interact with each other or intermolecular or intramolecular disulfide bonds would be formed at sites different from those observed in the natural one. As a result, not the desired natural protein but an associated or denatured one would be frequently obtained. In the case of a protein having a marked tendency to form an associated or denatured material through the interaction between hydrophobic groups,
35   in particular, the formation of disulfide bonds at the same sites as those of the natural one is considerably suppressed and thus the desired natural protein is obtained sometimes at a yield as low as approximately 1%.
    Therefore, it is difficult to efficiently reactivate a reduced and denatured cysteine-containing protein, which is liable to be converted into an associated or denatured one, by the interaction between hydrophobic
40   groups by a conventional reactivating process.
    K.E. Langley et al. reported that a protein can be reactivated by forming disulfide bonds in a denatured protein at the same sites as those of the corresponding natural protein and at a high frequency, compared with the case in which the formation of disulfide bonds at the same sites as those of the natural one is inhibited by the formation of an associated or denatured one through the interaction between hydrophobic
45   groups.
    The process for reactivating bovine growth hormone of K.E. Langley et al. comprises (1) washig proteinaceous inclusion bodies produced within the cells of Escherichia coli, followed by solubilizing the inclusion bodies in 6 M guanidine hydrochloride; (2) oxidizing the inclusion bodies by allowing to stand at room temperature for 20 hours or more so that the formation of disulfide bonds occurs; (3) subjecting to gel
50   filtration in the presence of 6 M guanidine hydrochloride; (4) collecting the monomer-containing fractions; and (5) diluting the fractions to the extent that the guanidine hydrochloride concentration is 2 M, followed by dialysis [K.E. Langley et al., Eur. J. Biochem., 163, 313-321 (1987)]. However, this process has such a disadvantage that since no reducing agent is added at the solubilization of the inclusion bodies, yields of the reduced monomer are low and formation of disulfide bonds at the same sites as those of the natural one is inhibited due to the action of the associated materials of the desired protein and substances

contaminating the inclusion bodies which undesirably block the SH groups of the desired protein. Also, during oxidation of the inclusion bodies by allowing to stand at room temperature for 20 hours or more, aspargine residues and glutamine residues are deamidated [Biochemica. et Biophysica. Acta., 214, 498-508 (1970)]. If the oxidation is carried out at a low temperature, i.e., about 5°C, in order to prevent the aspargine and glutamine residues from deamidation, it would take a prolonged time for oxidation.
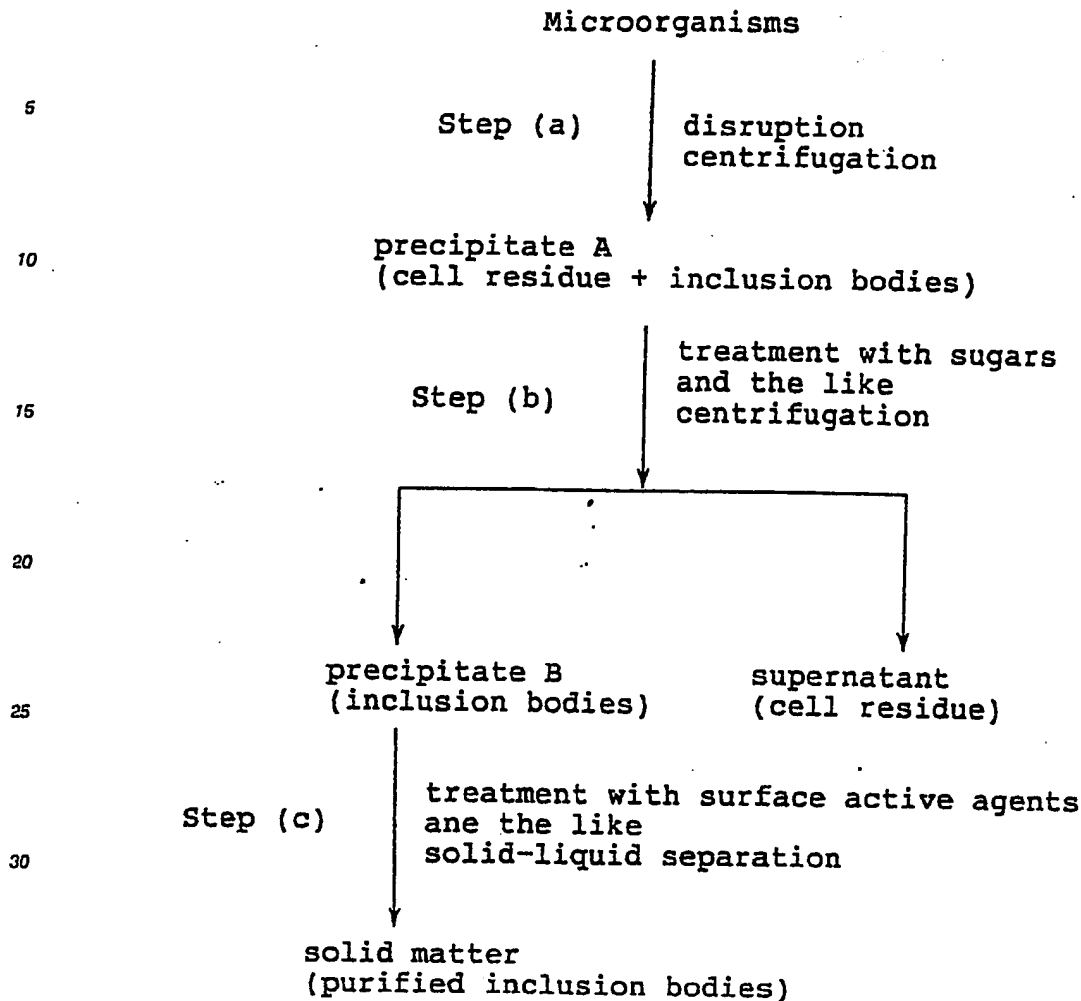
SUMMARY OF THE INVENTION

An object of the present invention is to provide a process for reactivating a reduced and denatured cysteine-containing protein in the desired natural form at a high yield.

We have found that reduced monomer of cysteine-containing protein can increase and the associated materials of the protein can decrease or disappear by adding a reducing agent as well as a denaturing agent at the sulbilization of the protein. Also, we have found that substances contaminating the inclusion bodies of the desired protein produced within the cells of microorganisms, which undesirably block the SH groups of the desired protein, can be dissociated from the desired protein, by adding a reducing agent as well as a denaturing agent at the solubilization of the inclusion bodies, and the substances can be removed together with the reducing agent. As the result, the denatured cysteine-containing protein can be reactivated in the desired natural form at high yield when disulfide bonds are formed in the denatured protein at the same sites as those of the corresponding natural protein. Thus, the present invention was completed.

The process of the present invention comprises the operative steps of: (1) converting a cysteine-containing protein into a reduced and denatured one by adding a denaturing agent and a reducing agent thereto to solubilize the same; (2) removing the reducing agent; (3) oxidizing the protein as denatured to form disulfide bonds at the same sites as those observed in the corresponding natural protein; and (4) removing the denaturing agent to isolate and purify the desired reactivated natural protein. The process of the present invention is particularly suitable for reactivating slightly soluble cysteine-containing proteins having few disulfide bonds and no intermolecular disulfide bond, which is liable to be converted into an associated or denatured one when reactivated in the presence of a denaturing agent at a low concentration, such as salmon growth hormone I (SGH-I) or eel growth hormone I.

DETAILED DESCRIPTION OF THE INVENTION

The protein in the form of inclusion bodies produced within the cells of microorganisms can be isolated and purified in accordance with the following method as described in JP-A-60-244259.

Microorganisms

Step (a) | disruption
centrifugation

precipitate A
(cell residue + inclusion bodies)

Step (b) | treatment with sugars
and the like
centrifugation

precipitate B   supernatant
(inclusion bodies)   (cell residue)

Step (c) | treatment with surface active agents
ane the like
solid-liquid separation

solid matter
(purified inclusion bodies)

Each step of the isolation and purification of inlcusion bodies is described in detail below.

In step (a), the cells of microorganisms in which the proteinaceous inclusion bodies have been produced are disrupted and centrifuged to obtain precipitate (precipitate A).

The cells are suspended in a buffer solution having a neutral pH value (e.g., phosphate buffer having a pH value of 7) and subjected to various known disruption method such as sonication, lysozyme treatment, homogenization, disruption by mechanical compression. The cell disruption is preferably carried out using the compressor such as French press, Manton-Gaulin homogenizer under the appropriate conditions for each apparatus.

Then, the thus-obtained suspension is centrifuged to give precipitate A which contains proteinaceous inclusion bodies and cell residues. Centrifugation can be carried out using the conventional centrifuge generally at 2,000 to 15,000 rpm for 10 to 120 minutes, and preferably at 4,000 to 12,000 rpm for 30 to 90 minutes. Continuous type centrifuge such as a centrifuge using Scharples® can also be employed.

In step (b), the precipitate A thus obtained is suspended in an aqueous solution having dissolved therein solute selected from an alkali metal or alkaline earth metal salt of an inorganic acid, sugars such as pentose, hexose, di-saccharides, trisaccharides, deoxysugars, sugar alcohols, dextran, dextrin, or Ficoll®, or Percoll®. Then, the suspension is centrifuged to obtain precipitate B containing protenaceous inclusion bodies. Supernatant containing cell residues is decanted. Conventionally, separation of cell components each of which has different density is conducted utilizing sucrose density-gradient centrifugation method, sucrose density-gradient equilibrium centrifugation method, or differential centrifugation method which comprises homogenizing rat liver in a sucrose-containing solution and centrifuging the homogenate to obtain precipitate containing cell nucleus [as described in Nozomi Otake et al., "Busshitsu no Tanri to Seisei (Isolation and Purification of Substances)", edited by Todai Shuppan. 145-155 (1977)].

In alkali metal or alkaline earth metal salts of an inorganic acid, examples of alkali metal or alkaline

earth metal include sodium, potassium, calcium and cesium and examples of an inorganic acid include hydrochloric acid, sulfuric acid and hydrobromic acid. Specific examples of these salts include cesium chloride, calcium sulfate, sodium chloride and sodium bromide.

Examples of sugars include pentose such as L-arabinose, D-xylose and D-ribose; hexose such as D-glucose, D-mannose, D-galactose, L-galactose, D-fructose and L-sorbose; di- or trisaccharides such as sucrose, maltose, lactose, trehalose, cellobiose and raffinose; deoxysugars such as L-rhamnose and 2-deoxy-D-ribose; and sugar alcohols such as glycerol, erythritol, arabitol, D-sorbitol and D-mannitol.

Ficoll and Percoll are trade names of the products manufactured by Pharmacia Fine Chemicals. Ficoll is a highly water-soluble sinthetic macromolecule consisting of sucrose and epichlorohydrin. Percoll is of uniform particle size of silica beads coated with synthetic resin.

Solvents for the solution (suspension) containing the above-described solutes are preferably buffer solutions having a neutral pH value.
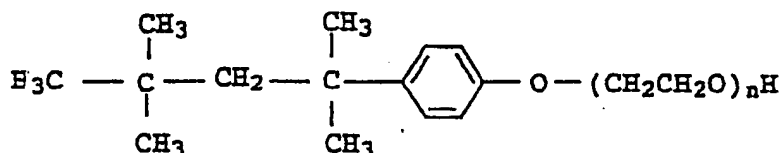
The solid concentration of the solution (suspension) ranges from 5 to 50 w/w% in the case of alkali metal or alkaline earth metal salts of inorganic acid; 10 to 80 w/w% in the case of glycerol; 5 to 50 w/w% in the case of dextran or destrin; 0.25 to 4 M, preferably 0.5 to 2 M in the case of the other sugars. The solution or suspention is used in an amount of 1/20 to 20-folds (v/v) of the starting volume of cultures applied to step (a).

The thus-obtained suspension of precipitate A may be immediately subjected to centrifugation to obtain precipitate B. Preferably, the suspension is centrifuged after sufficient agitation for effective separation of precipitate B. The centrifugation can be carried out using the conventional centrifuge at 2,000 to 15,000 rpm for 10 to 120 minutes, preferably at 4,000 to 12,000 rpm for 30 to 90 minutes. Continuous type centrifuge such as a centrifuge using Scharples® can also be used.

In step (c), precipitate B is mixed with an aqueous solution containing a nonionic surface active agent, or cholic acids or an alkali metal salt of cholic acid, followed by solid-liquid separation to thereby remove the membrane components (including protein, lipid or lipopolysaccharide) of microorganisms contaminating precipitate B and purify the inclusion bodies.

Lipopolysaccharide is known as pyrogen and therefore, it is necessary to remove lipopolysaccharide from the inclusion bodies in view of use for pharmaceutical preparations. Schnaitman reported that proteins, lipids and lipopolysaccharides can be removed from the membrane of Escherichia coli by treating with Triton X-100, EDTA, etc. [J. Bacteriology, 108, 553 (1971)].

Examples of nonionic surface active agents include polyoxyethylene alkyl ethers such as polyoxyethylene oleyl ether [$C_{18}H_{35}O(CH_2CH_2O)_nH$, trade name: Brij 96 (n = 10), Brij 98 (n = 20), etc.], polyoxyethylene fatty acid esters such as polyoxyethylene stearate (trade name: Nissan nonion S) polyoxyethylene alkyl phenyl ethers such as polyoxyethylene p-t octylphenyl ether represented by the formula

$$H_3C - \underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}} - CH_2 - \underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}} - \langle\!\!\!\!\!\!\!\!\!\!\!\!\bigcirc\!\!\!\!\!\!\!\!\!\!\!\!\rangle - O - (CH_2CH_2O)_nH$$

(trade name: Triton X-100 (n = 9, 10), sorbitan fatty acid esters such as sorbitan monostearate (trade name: Span 60), polyoxyethylene sorbitan fatty acid esters such as polyoxyethylene sorbitan monolaurate [trade name: Tween 20 (having 20 units of oxyethylene)].

Examples of cholic acid or alkali metal salt thereof include cholic acid, deoxycholic acid and sodium salt thereof.

These surface active agents (including cholic acid and alkali metal salt thereof) are preferably dissolved in a buffer solution having a neutral pH value so as to give a final concentration of 0.2 to 10 w/v%, preferably 0.5 to 4 w/v%.

The thus-obtained mixture containing precipitate B can be immediately subjected to solid-liquid separation. Preferably, the separation is performed after the mixture is sufficiently agitated for efficient separation.

The solid-liquid separation can be effected by centrifugation or filtration. The conditions for the centrifugation is not restricted as long as liquid and solid can be separated. For example, centrifugation method as described in steps (a) and (b) can be employed.

At the treatment with the surface active agent, a metal chelating agent can be used in combination for efficient purification.

Examples of the metal chelating agent include EDTA (ethylenediaminetetraacetic acid), EGTA [ethyleneglucose bis(2-aminoethylene)tetraacetic acid], NTA (nitrilotriacetic acid), HEDTA (2-hydroxyethylethylenediaminepentaacetic acid), DCTA (1,2-diaminocyclohexanetetraacetic acid). The concentration of the metal chelating agent ranges from 2 to 50 mM, preferably 5 to 20 mM. The other conditions can be

5 the same as those described in the case that the surface active agent is used alone.

The thus-recovered proteinaceous inclusion bodies are solubilized by adding a reducing and a denaturing agent.

One or more materials selected from among SDS (sodium dodecyl sulfate), urea, guanidine hydrochloride, acids and alkalis are employed as a denaturing agent. The denaturing agent and its concentration are

10 selected in such a manner as to render the protein to be solubilized as uniform as possible. When acids or alkalis are used as a denaturing agent, solvents used are not particularly restricted. When the denaturing agent other than acids and alkalis are used, preferable examples of the solvents are buffer solutions having an approximately neutral pH value (e.g., a phosphate buffer having a pH value of 7). The reducing agent, which may be selected from, for example, monovalent thiols such as β-mercaptoethanol, cysteine and

15 glutathione or dithiothreitol (DTT), is added to an aqueous solution containing the denaturing agent. Among these substances, DTT is particularly preferable since it has little tendency to form a disulfide bond with a cysteine residue of a protein.

By adding a reducing agent as well as a denaturing agent at the solubilization of a protein, reduced monomer of the protein can increase and the associated materials of the protein can decrease or disappear.

20 Substances contaminating the inclusion bodies of the desired protein produced within the cells of microorganisms, which undesirably block the SH groups of the desired protein, can also be dissociated from the desired protein, by adding a reducing agent as well as a denaturing agent at the solubilization of the inclusion bodies.

The reducing agent may be removed by, for example, dilution, dialysis involving ultrafiltration, gel

25 filtration, chromatography involving absorption/desorption or a batch process, each in the presence of a denaturing agent under non-oxidizing conditions, though it is not restricted thereby. Gel filtration is particularly preferable.

Also, the substances contaminating the inclusion bodies produced within the cells of microorganisms, which block the SH groups of the desired protein, can be removed together with the reducing agent.

30 The oxidation process is not particularly restricted. It may be carried out spontaneously. Alternately, it may be effected by bubbling oxygen or air into the aqueous solution to accelerate the oxidation by the dissolved oxygen; adding divalent copper ions to the aqueous solution to accelerate the oxidation by the dissolved oxygen; or by adding a weak oxidizing agent such as of iodosobenzoic acid, oxidized glutathione, a mixture of oxidized glutathione and reduced glutathione, cystine or a mixture of cystine and cysteine to

35 the aqueous solution. It is further possible to control the oxidation rate by adjusting the pH value. At the oxidation, it is preferable that the protein concentration is as low as possible. The protein concentration may be 0.1 to 2,000 μg/mℓ in general, though it may vary depending on the protein to be recovered. The reaction period and reaction temperature are not particularly restricted. It is generally preferable to effect the reaction at a temperature of below 10°C without freezing the reaction solution for five minutes to ten

40 hours. By this oxidation, a protein having disulfide bonds at the same sites as those observed in the corresponding natural protein at a high frequency is formed.

The denaturing agent may be removed by, for example, dilution, dialysis involving ultrafiltration, gel filtration, isoelectric precipitation, chromatography involving absorption/desorption or a batch process. Thus, associated or denatured proteins having disulfide bonds at sites different from those observed in the natural

45 one, as well as impurities, are removed together with the denaturing agent, since these materials are different in, for example, molecular weight, charge or hydrophobic nature from the desired protein. Thus, the protein having disulfide bonds at the same sites as those observed in the corresponding natural protein can be readily and reliably isolated. More particularly, the isolation may be carried out by, for example, (a) dialysis/centrifugation, (b) dilution/concentration/isoelectric precipitation/centrifugation, (c) ion exchange

50 chromatography/dialysis/centrifugation, or (d) gel filtration/ion exchange chromatography.

Through the process of the present invention, the reaction temperature is not particularly restricted. Preferably, the reaction can be carried out at a temperature of below 10°C without freezing the reaction solution. The pH value of a solution containing the protein to be reactivated is not particularly restricted, but it varies depending on the kind of the protein. Preferably, the pH value of the solution ranges from 2 to 10.

55 To further illustrate the present invention, and not by way of limitation, the following examples will be given.

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EXAMPLE 1

Reactivation of SGH-I from inclusion bodies produced by E. coli

Recombinant SGH-I was isolated from recombinant SGH-I inclusion body-containing cells obtained by a culture method described in JP-A-61-93197 and purified to a purity of 90% according to a method described in JP-A-60-224259. 5 mg of these inclusion bodies were dissolved in a 100 mM tris-(hydroxymethyl)aminomethane buffer solution (pH 8.0) containing 7 M of urea, 5 mM of EDTA and 1 mM of DTT to give a volume of 2.5 mℓ. The resulting solution was stirred at 4°C for two hours and then centrifuged at 12,000 rpm for five minutes. The reducing agent was removed from the supernatant using a gel filtration column PD-10 (manufactured by Pharmacia Fine Chemicals) which had been equilibrated with a 100 mM tris buffer solution (pH 7.0) containing 7 M of urea. 3.5 mℓ of the protein-containing fraction thus obtained was mixed with the equivalent amount of a 100 mM tris buffer solution (pH 9.0) containing 7 M of urea and 1 mM of $CuSO_4$ and the obtained mixture was allowd to stand at 4°C for two hours to thereby allow the oxidation to proceed. Then, 7 mℓ of this solution was dialyzed against 2 ℓ of a 100 mM tris buffer solution (pH 7.0) at 4°C overnight. After centrifuging the internal solution at 12,000 rpm for five minutes, almost pure recombinant SGH-I was collected in the supernatant. The activity of the recombinant SGH-I thus obtained was determined according to the process reported by Sekine et al. (cf. Proc. Natl. Acad. Sci. USA, 82, 4306 (1985)). As a result, the obtained recombinant SGH-I showed an activity comparable to that of natural SGH-I reported by H. Kawauchi et al. [cf. Archives of Biochem. and Biophys., 244, 542 (1986)]. Table 1 shows the yields.

Table 1

Reactivation of salmon growth hormone I		
Steps of Reactivation	Volume (mℓ)	Protein* (μg)
inclusion body solution	2.5	1,130
gel filtration fraction	3.5	915
oxidized solution	7.0	900
dialyzed and centrifuged supernatant	7.5	503

* Note: amount of salmon growth hormone I.

EXAMPLE 2

Purification of natural SGH-I after oxidation step (I)

The oxidized solution obtained in Example 1 was diluted 10-fold with a 100 mM tris buffer solution (pH 8.0) and allowed to stand at 4°C for two hours. Then, it was concentrated to 1/10 by using an ultrafiltration membrane (YM-10: manufactured by Amicon). The pH value of the concentrate was adjusted to 6.0 with 1 N- hydrochloric acid to thereby induce isoelectric precipitation. After centrifuging at 12,000 rpm for five minutes, almost pure recombinant SGH-I was collected in the supernatant. The activity of the recombinant SGH-I thus obtained was determined according to the process reported by Sekine et al. [cf. Proc. Natl. Acad. Sci. USA., 82, 4306 (1985)]. As a result, the obtained recombinant SGH-I showed an activity comparable to that of natural SGH-I as reported by H. Kawauchi et al. [cf. Archives of Biochem. and Biophys., 244, 542 (1986)]. Table 2 shows the yields.

Table 2

Reactivation of salmon growth hormone I		
Steps of Reactivation	Volume (m ℓ)	Protein* (μg)
oxidized solution	7.0	900
isoelectric-precipitated and centrifuged supernatant	7.8	473

* Note: amount of salmon growth hormone I.

EXAMPLE 3

Purification of natural SGH-I after oxidation step (II)

The oxidized solution obtained in Example 1 was diluted 10-fold with 7 M urea and the pH value of the obtained solution was adjusted to 8.0. Then, the solution was passed through a DEAE Sepharose® CL-6B column (1.5 x 5.7 cm, manufactured by Pharmacia Fine Chemicals), which had been equilibrated with a 10 mM tris buffer (pH 8.0) containing 7 M urea, at a rate of 10 m ℓ/hr. The column was then washed with 50 m ℓ of the above buffer solution at a rate of 10 m ℓ/hr and subsequently eluted by a concentration gradient method with the use of 30 m ℓ of the above buffer solution and a 10 mM tris buffer solution (pH 8.0) containing 7 M of urea and 1 M of NaC ℓ at at rate of 5 m ℓ/hr. The elute was fractionated by 5 m ℓ portions. As a result, almost pure recombinant SGH-I was collected in the third fraction (5 m ℓ). 5 m ℓ of this fraction was dialyzed against 1.5 ℓ of a 100 mM tris buffer (pH 8.0) at 4°C overnight. The internal solution was centrifuged at 12,000 rpm for five minutes. Recombinant SGH-I having the same stereostructure involving the position of disulfide bonds as natural SGH-I was collected in the supernatant. The activity of the recombinant SGH-I obtained was determined according to the process reported by Sekine et al. [cf. Proc. Natl. Acad. Sci. USA., 82, 4306 (1985)]. As a result, the obtained recombinant SGH-I showed an activity comparable to that of natural SGH-I as reported by H. Kawauchi et al. [cf. Archives of Biochem. and Biophys., 244 542 (1986)]. Table 3 shows the yields.

Table 3

Reactivation of salmon growth hormone I		
Steps of Reactivation	Volume (m ℓ)	Protein* (μg)
oxidized solution	7.0	900
DEAE-elution fraction	5.0	433
dialyzed and centrifuged supernatant	7.8	389

* Note: amount of salmon growth hormone I.

EXAMPLE 4

Reactivation of eel growth hormone I from inclusion bodies produced by E. coli

Recombinant eel growth hormone I inclusion bodies were obtained by the following method. E. coli EUPA1 (FERM BP-825) was inoculated into 10 mℓ of an MCG medium (pH 7.2) comprising 0.6% of Na₂HPO₄, 0.3% of KH₂PO₄, 0.5% of NaCℓ, 0.1% of NH₄Cℓ, 0.5% of glucose, 0.5% of Casamino acid, 1 mM of MgSO₄ and 4 µg/mℓ of vitamin B₁ and cultured in the medium at 30° C for seven hours. The culture thus obtained was inoculated into 50 mℓ of an MCG medium and further cultured in it at 30° C for 18 hours. The culture obtained was inoculated into 1 ℓ of an MCG medium and further cultured therein at 30° C for five hours, then at 42° C for two hours and finally at 37° C for 41 hours. The culture thus obtained was centrifuged at 8,000 rpm for ten minutes to collect the cells. From these cells, eel growth hormone I inclusion bodies were isolated and purified at a purity of approximately 90% according to a method described in JP-A-60-244259.

5 mg of these inclusion bodies were dissolved in a 100 mM tris buffer solution (pH 8.0) containing 7 M of urea, 5 mM of EDTA and 1 mM of DTT to give a volume of 2.5 mℓ. The resulting solution was stirred at 4° C for two hours and then centrifuged at 12,000 rpm for five minutes. DTT was removed from the supernatant by using a gel filtration column PD-10 (manufactured by Pharmacia Fine Chemicals) which have been equilibrated with a 100 mM tris buffer solution (pH 7.0) containing 7 M of urea. 3.5 mℓ of the protein-containing fraction thus obtained was mixed with the equivalent amount of a 100 mM tris buffer solution (pH 9.0) containing 7 M of urea and 1 mM of CuSO₄ and the obtained mixture was allowed to stand at 4° C for two hours to thereby allow the oxidation to proceed. Subsequently, 7 mℓ of this solution was dialyzed against 2 ℓ of a 100 mM tris buffer solution (pH 7.0) at 4° C overnight. After centrifuging the internal solution at 12,000 rpm for five minutes, almost pure recombinant eel growth hormone I was collected in the supernatant. The antibody-binding activity of the recombinant eel growth hormone I thus obtained was determined according to the radioimmunoassay reported by M. Kishida et al. [cf. General and Comparative Endocrinol., 65, 478 (1987)]. As a result, the obtained eel growth hormone I showed a biological activity comparable to that of natural eel growth hormone I reported by M. Kishida et al. [cf. General and Comparative Endocrinol., 65, 478 (1987)]. Table 4 shows the yields.

Table 4

Reactivation of eel growth hormone I		
Steps of Reactivation	Volume (mℓ)	Protein* (µg)
inclusion body solution	2.5	1,050
gel filtration fraction	3.5	930
oxidized solution	7.0	912
dialyzed solution	7.8	820

* Note: amount of eel growth hormone I.

EXAMPLE 5

Reactivation of SGH-I from inclusion bodies produced by E. coli

Recombinant SGH-I was isolated from recombinant SGH-I inclusion body-containing cells obtained by a culture method described in JP-A-61-93197 and purified to a purity of 90% according to a method described in JP-A-60-244259. 5 mg of these inclusion bodies were dissolved in a 100 mM tris buffer solution (pH 8.0) containing 7 M of urea, 5 mM of EDTA and 1 mM of DTT to give a volume of 2.5 mℓ. The resulting solution was stirred at 4° C for two hours and then centrifuged at 12,000 rpm for five miutes. DTT was removed from the supernatant using a gel filtraiton column PD-10 (manufactured by Pharmacia Fine Chemicals) which had been equilibrated with a 100 mM tris buffer solution (pH 7.0) containing 7 M of urea. 3.5 mℓ of the protein-containing fraction thus obtained was mixed with the equivalent amount of a 100 mM

tris buffer solution (pH 9.0) containing 7 M urea and 0.2 mM of oxidizing glutathione and the resulting mixture was stirred at 4°C overnight to thereby allow the oxidation to proceed. Subsequently. 7 mℓ of this solution was dialyzed against 2 ℓ of a 100 mM tris bufer solution (pH 7.0) at 4°C overnight. After centrifuging the internal solution at 12.000 rpm for five minutes, almost pure recombinant SGH-I was
5 collected in the supernatant. The activity of the recombinant SGH-I thus obtained was determined according to the process reported by Sekine et al. [cf. Proc. Natl. Acad. Sci. USA., 82, 4306 (1985)]. As a result. the obtained recombinant SGH-I showed an activity comparable to that of natural SGH-I as reported by H. Kawauchi et al. [cf. Archives of Biochem. and Biophys., 244, 542 (1986)]. Table 5 shows the yields.

10   Table 5

Reactivation of salmon growth hormone I		
Steps of Reactivation	Volume (mℓ)	Protein* (μg)
inclusion body solution	2.5	1.130
gel filtration fraction	3.0	915
oxidized solution	7.0	900
dialyzed and centrifuged supenatant	7.5	510

* Note: amount of salmon growth hormone I.

25   REFERENCE EXAMPLE 1

30 Reactivation of salmon growth hormone I by conventional method

    5 mg of SGH-I inclusion bodies obtained in the same manner as the one described in Example 1 were dissolved in a 100 mM tris buffer solution (pH 8.0) containing 7 M of urea, 5 mM of EDTA and 1 mM of
35 DTT to give a volume of 12.5 mℓ. The obtained solution was stirred at 4°C for two hours and centrifuged at 12.000 rpm for five minutes. The supernatant was dialyzed against 3 ℓ of a 100 mM phosphate buffer solution (pH 7.0) at 4°C overnight. The internal solution was centrifuged at 12.000 rpm for five minutes to give the supernatant. Table 6 shows the yields. Although the supernatant contains almost pure recombinant SGH-I, the yield was extremely low. Thus, this process was not effective in practice.

40   Table 6

Reactivation of salmon growth hormone I (conventional method)		
Steps of Reactivation	Volume (mℓ)	Protein* (μg)
inclusion body solution	12.5	1,040
dialyzed solution	13.0	111

* Note: amount of salmon growth hormone I.

55   REFERENCE EXAMPLE 2

Reactivation of eel growth hormone I by conventional method

5 mg of recombinant eel growth hormone I inclusion bodies obtained in the same manner as the one described in Example 4 were dissolved in a 100 mM tris buffer solution (pH 8.0) containing 7 M of urea, 5 mM of EDTA and 1 mM of DTT to give a volume of 12.5 ml. The obtained solution was stirred at 4°C for two hours and centrifuged at 12,000 rpm for five minutes. The supernatant was dialyzed against 3 ℓ of a 100 mM phosphate buffer solution (pH 7.0) at 4°C overnight. The internal solution was centrifuged at 12,000 rpm for five minutes to give the supernatant. Table 7 shows the yields. Although the supernatant contains almost pure recombinant eel growth hormone I, the yield was extremely low. Thus, this process was not effective in practice.

Table 7

Reactivation of eel growth hormone I (conventional method)		
Steps of Reactivation	Volume (ml)	Protein* (µg)
Inclusion body solution	12.5	1,070
dialyzed solution	13.0	325

* Note: amount of eel growth hormone I.

According to the present invention, a reduced and denatured cysteine-containing protein can be efficiently reactivated.

REFERENCE EXAMPLE 3

Reactivation of salmon growth hormone I by method of K.E. Langley et al [Eur. J. Biochem., 163, 313-321 (1987)]

100 mg of SGH-I inclusion bodies obtained in the same manner as the one described in Example 1 were dissolved in a 50 mM tris hydrochloride buffer solution (pH 8.0) containing 6 M of guanidine hydrochloride to give a volume of 10 mℓ. After allowing to stand for 80 hours, the SGH-I-containing solution was passed through a Sephacryl S-200® column (2.6 × 94 cm, manufactured by Pharmacia Fine Chemicals), which had been equilibrated with the above-described tris hydrochloride buffer at a rate of 50 mℓ/hr and subsequently eluted with the same buffer. The elute was fractionated by 5 mℓ portions to obtain a total volume of the fraction of 35 mℓ. To this fraction, a buffer solution (pH 8.5) containing 0.25 w/v% of NaHCO₃, 0.2 w/v% of α-lactose and 0.2 w/v% of mannitol were added to give a final volume of 105 mℓ. Then, the thus-obtained solution was dialyzed against 30 ℓ of the above-described buffer at room temperature for 24 hours. The internal solution was centrifuged to obtain the supernatant. Table 8 shows the yields. Although almost pure recombinant SGH-I was recovered in the supernatant, the yield was extremely low. Thus, this process was not effective in practice.

Table 8

Reactivation of salmon growth hormone I		
Steps of Reactivation	Volume (ml)	Protein* (µg)
inclusion body solution	10	22,600
oxidized solution	10	22,600
gel filtration fraction	35	9,100
dialyzed and centrifuged supenatant	110	5,500

* Note: amount of salmon growth hormone I.

While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof.

Claims

1. A process for reactivating a protein in its natural form which comprises the steps of:
(1) converting a cysteine-containing protein into the corresponding reduced and denatured one by adding a denaturing agent and a reducing agent thereto to solubilize the protein;
(2) removing the reducing agent;
(3) oxidizing the cysteine-containing protein, as denatured, to form disulfide bonds at the same sites as those observed in the corresponding natural protein; and
(4) removing the denaturing agent to thereby isolate and purify the reactivated protein.

2. A process of recovering a cysteine-containing protein in its natural form from inclusion bodies produced within the cells of a microorganism, said process comprising the steps of:
(1) removing cysteine-containing protein inclusion bodies having disulfide bonds from the cells of a microorganism;
(2) uniformly solubilizing the proteinaceous inclusion bodies by adding a reducing and a denaturing agent thus reducing and denaturing the cysteine-containing protein and solubilizing it;
(3) removing the reducing agent;
(4) oxidizing the denatured cysteine-containing protein from step (3) to form disulfide bonds at the same sites as those observed in the corresponding natural protein; and
(5) removing the denaturing agent and any associated or denatured proteins having disulfide bonds at sites different from those observed in the natural protein and impurities present to thereby isolate the desired reactivated and purified protein having disulfide bonds at the same sites as those observed in the corresponding natural protein.

3. A process as set forth in claim 1 or 2, wherein said denaturing agent is selected from the group consisting of SDS, urea, guanidine hydrochloride, acids and alkalis.

4. A process as set forth in claim 1 or 2, wherein the reducing agent is removed by dilution, dialysis, ultrafiltration, gel filtration, adsorption/desorption chromatography or a batch processing in the presence of a denaturing agent under non-oxidizing conditions.

5. A process as set forth in claim 1 or 2, wherein the reducing agent is removed by gel filtration in the presence of a denaturing agent under non-oxidizing conditions.

6. A process as set forth in claim 1 or 2, wherein the oxidation process is spontaneous.

7. A process as set forth in claim 1 or 2, wherein said oxidation is carried out by a method selected from the group consisting of air-oxidation with aeration, air-oxidation with the use of a metal ion as a catalyst, and oxidation with the use of a weak oxidizing agent.

8. A process as set forth in claim 7, wherein said weak oxidizing agent is selected from the group consisting of o-iodosobenzoic acid, oxidized glutathione, a mixture of oxidized glutathione and reducing glutathione, cystine or a mixture of cystine and cysteine.

9. A process as set forth in claim 1 or 2, wherein the protein concentration during the oxidation step is from about 0.1 to about 2,000 µg/ml.

10. A protein obtainable according to the method of anyone of claims 1 to 9.